

## MANIPULATING CONSCIOUSNESS

E. A. Novikov

Institute for Nonlinear Science, University of California - San Diego, La Jolla, CA 92093 - 0402

Manipulation of the effects of consciousness by external influence on the human brain is considered in the context of the nonlinear dynamical modeling of interaction between automatic and conscious processes.

In previous papers [1,2] an approach to nonlinear dynamical modeling of interaction between automatic (A) and conscious (C) processes in the brain was presented. The idea is to use quaternion field with real and imaginary components representing A - and C - processes. The subjective C - experiences were divided into three major groups: sensations (S), emotions (E) and reflections (R). Note, that subjective S should be distinguished from the automatic sensory input into the neuron system of the brain. The A - C interaction is due to the nonlinearity of the system. This approach was illustrated on the nonlinear equation for the current density in the cortex. The nonlinearity is determined by the sigmoidal firing rate of neurons. Perspective for testing of this approach were also indicated as well as some more general approaches [1,2].

For the purpose of medical and other possible applications it is interesting to include an external electromagnetic (EM) influence in this modeling. In a laboratory setting a specially equipped helmet can produce designed nonhomogeneous or homogeneous excitations in the brain. On another hand, suppose we want to pacify a group of terrorists (!) by using a strong EM radiation with the wavelength much larger than the size of their brains. In this case the excitation will be approximately homogeneous. We start with the homogeneous case which is more simple mathematically and gives some insight into general situation.

The model equation for the average (spatially uniform) current density  $\alpha(t)$  perpendicular to the cortical surface has the form [1,2]:

$$\frac{\partial \alpha}{\partial t} + k\alpha = \text{Re}\{f(\alpha + \sigma + i_p \psi_p)\} + \varphi \quad ((1))$$

Here  $k$  is the relaxation coefficient,  $\sigma(t)$  is the average sensory input,  $f$  represents the sigmoidal firing rate of neurons [for example,  $f(\alpha) = \tanh(\alpha)$ ], components  $\psi_p$  represent the indicated above (S, E, R) - effects and summation is assumed on repeated subscripts from 1 to 3. The quaternion imaginary units  $i_p$  satisfy conditions:

$$i_p i_q = \varepsilon_{pqr} i_r - \delta_{pq} \quad ((2))$$

where  $\varepsilon_{pqr}$  is the unit antisymmetric tensor and  $\delta_{pq}$  is the unit tensor. Formula (2) is a compact form of conditions:  $i_1^2 = i_2^2 = i_3^2 = -1$ ,  $i_1 i_2 = -i_2 i_1 = i_3$ ,  $i_2 i_3 = -i_3 i_2 = i_1$ ,  $i_3 i_1 = -i_1 i_3 = i_2$ . Equation (1) is obtained by using the quaternion  $q = \alpha + i_p \psi_p$  instead of  $\alpha$  in order to describe the A - C interaction. The additional term  $\phi$  in (1) represents the external EM excitation. Equation (1) is the real part of the equation for the quaternion [1,2]:

$$\frac{\partial q}{\partial t} + kq = f(q + \sigma) + \phi \quad ((1a))$$

For  $\psi_p$  from (1a) we have equations:

$$\frac{\partial \psi_p}{\partial t} + k\psi_p = \text{Im}_p\{f(\alpha + \sigma + i_q \psi_q)\}, \quad p = 1, 2, 3 \quad ((3))$$

where  $\text{Im}_p\{f\} = -\text{Re}\{fi_p\}$ . Note, that so-called extra-sensory effects (if they exist) can be included in this approach by assuming that  $\sigma$  is a quaternion:  $\sigma \Rightarrow \sigma + i_p s_p$ , this will produce shift  $\psi_p \Rightarrow \psi_p + s_p$  in the nonlinear terms in (1), (3) and below in (5), (6).

Let us consider typical  $f(\alpha) = \tanh(\alpha)$ . Simple algebra gives [2]:

$$\tanh(q) = \frac{\sinh(2\alpha) + j \sin(2\psi)}{\cosh(2\alpha) + \cos(2\psi)}, \quad \psi^2 \equiv \psi_p^2, \quad j \equiv i_p \psi_p \psi^{-1}, \quad j^2 = -1 \quad ((4))$$

Using (4) with shift  $\alpha \Rightarrow \alpha + \sigma$ , we rewrite (1) and (3) explicitly:

$$\frac{\partial \alpha}{\partial t} + k\alpha = \frac{\sinh[2(\alpha + \sigma)]}{\cosh[2(\alpha + \sigma)] + \cos(2\psi)} + \phi \quad ((5))$$

$$\frac{\partial \psi_p}{\partial t} + k\psi_p = \frac{\psi_p \psi^{-1} \sin(2\psi)}{\cosh[2(\alpha + \sigma)] + \cos(2\psi)}, \quad p = 1, 2, 3 \quad ((6))$$

Some general conclusions can be made without solving these equations. Firstly, if  $\psi_p(0) = 0$  than  $\psi_p(t) \equiv 0$  (unless  $s_p \neq 0$ ). Secondly, if  $\psi_p(0) \neq 0$ , than evolution  $\psi_p(t)$  can be manipulated by using sensory input  $\sigma(t)$  and EM excitation  $\phi(t)$ . Thirdly, the nonlinearity of the system suggests that the efficiency of such manipulation depends not only on the amplitudes of  $\sigma(t)$  and  $\phi(t)$  but also on the shape of these functions (spectral content).

For the case of spatially nonuniform  $\alpha(t, \mathbf{x})$ ,  $\psi_p(t, \mathbf{x})$ ,  $\sigma(t, \mathbf{x})$  and  $\phi(t, \mathbf{x})$  we can use more general equations, which include typical propagation velocity of signals in the neuron system of the cortex  $v$ . Time differentiation of (1a), simple algebra and addition a term with the two-dimensional spatial Laplacian  $\Delta$  gives [1,2]:

$$\frac{\partial^2 q}{\partial t^2} + (k + m) \frac{\partial q}{\partial t} + (km - v^2 \Delta)q = (m + \frac{\partial}{\partial t})f(q + \sigma) + \frac{\partial \phi}{\partial t} \quad ((7))$$

where  $m$  is an arbitrary parameter (see below). Real and imaginary projections of (7) give equations for  $\alpha$  and  $\psi_p$ , which are generalizations of (1) and (3). If we

put  $\psi_p = 0$  and  $\phi = 0$ , than equation for  $\alpha$  will be similar in spirit to equations used for interpretation of EEG and MEG spatial patterns ( see recent paper [3] and references therein). In this context we have parameters:  $k \sim m \sim v/l$ , where  $l$  is the connectivity scale. For  $f(\alpha) = \tanh(\alpha)$  the nonlinear term  $f(q+\sigma)$  in (7) has the same projections as in (5) and (6).

The obtained in this letter equations can be used for numerical experiments and for comparison with corresponding laboratory experiments.

### References

- [1] E. A. Novikov, Towards modeling of consciousness, arXiv:nlin.PS/0309043 (2003)
- [2] E. A. Novikov, Quaternion dynamics of the brain, arXiv:nlin.PS/0311047 (2003)
- [3] V. K. Jirsa, K. J. Jantzen, A. Fuchs, and J. A. Kelso, Spatiotemporal forward solution of the EEG and MEG using network modeling, IEEE Trans. Med. Imaging, **21**(5), 497 (2002)